CHAPTER VII

CARBONATE ROCKS

GENERAL

The formation of dolomitic rocks (Phoksing Dolomite) which overlies the black carbonaceous slates (Bihadi Slates), exposed in the southern extremity of the study area, extends in a E-W belt from end to end and continues beyond the study area. It is seen to be several hundred meters thick but the extensive isoclinal folding has rendered its true thickness difficult to be measured. The constituent rocks are gray,light gray to dark gray, massive to thickly bedded dolomites. The presence of algal laminae helps in identifying the bedding plane surfaces. The field characters of these rocks have already been described in Chapter III (Geological Setting).

These carbonate rocks comprise one of the important lithounits, and occupy almost one third of the mapped terrain. Except referring to these rocks as dolomitic in composition, earlier workers have not given any details. Therefore, the present author has attempted to find out the true nature of these dolomitic rocks on the basis of their petrographic character, chemical analysis, staining techniques, X-Ray and D.T.A. studies. Also, the palaeoenvironment of their deposition has been worked out.

CHEMICAL ASPECTS OF DOLOMITIC ROCKS

The chemical analyses of representative samples of dolomite rocks have been given in table VII.1. So far, no publisned literature is available on the chemistry of the dolomites of this area.

The plots of the CaO-MgO and insoluble residue compared with the average dolomites (Pettijohn, 1975) in a triangular diagram are shown in Fig. VII.1. The insoluble residue, CaO and MgO percentages vary greatly (Table VII.2). The insoluble residues are as low as 2.21 % in some dolomite rocks, while as high as 61.5 % in some cases (siliceous dolomite). Similarly CaO percentage varies from 11.00 to 29.82. Percentage of MgO also widely ranges from 8.62 to 21.79. There is a linear relationship between the MgO percentage and

Table VII.1 Chemical analysis of Dolomites of Kali Gandaki Valley (weight percent)

Sample No.	SiO_2	Al_2O_3	Fe_2O_3+ FeO	CaO	MgO	P_2O_5	Loss on igni-tion	Total
26	34.66	1.41	0.44	19.28	14.51	0.002	30.45	100.75
62	33.20	0.56	0.44	20.32	13.69	0.002	30.75	98.96
77	2.21	0.41	0.09	29.82	21.79	0.001	46.08	100.40
82	27.60	0.41	0.89	22.37	15.22	0.004	33.94	100.43
105	61.46	0.76	0.19	10.97	8.62	0.06	18.10	100.16
116	7.89	0.33	0.17	27.60	20.69	0.002	43.18	99.86
138B	15.73	0.59	0.16	25.31	18.30	0.00	39.58	99.67
144	9.50	0.62	0.18	26.14	20.23	0.002	42.60	99.27
172	5.45	0.60	0.25	29.53	19.47	0.002	44.20	99.50
188C	36.63	1.99	5.11	18.05	10.60	0.004	27.68	100.06
206	15.25	1.27	0.18	25.56	18.02	0.001	39.23	99.51
207	5.00	1.14	0.36	28.32	19.69	0.003	44.83	99.34
210	15.06	0.34	0.21	25.92	18.02	0.001	39.60	99.15
219	49.75	0.41	0.14	14.87	11.32	0.001	23.14	99.63
246	31.25	0.31	0.25	20.96	15.13	0.001	31.12	99.02
283	41.65	0.48	0.27	17.47	13.35	0.002	27.34	100.56

Analyst: B.N. Upreti

FIG. VII.1

TRIANGULAR DIAGRAM OF DOLOMITES
BASED ON $CaO - MgO - SiO_2$ WT. PERCENT

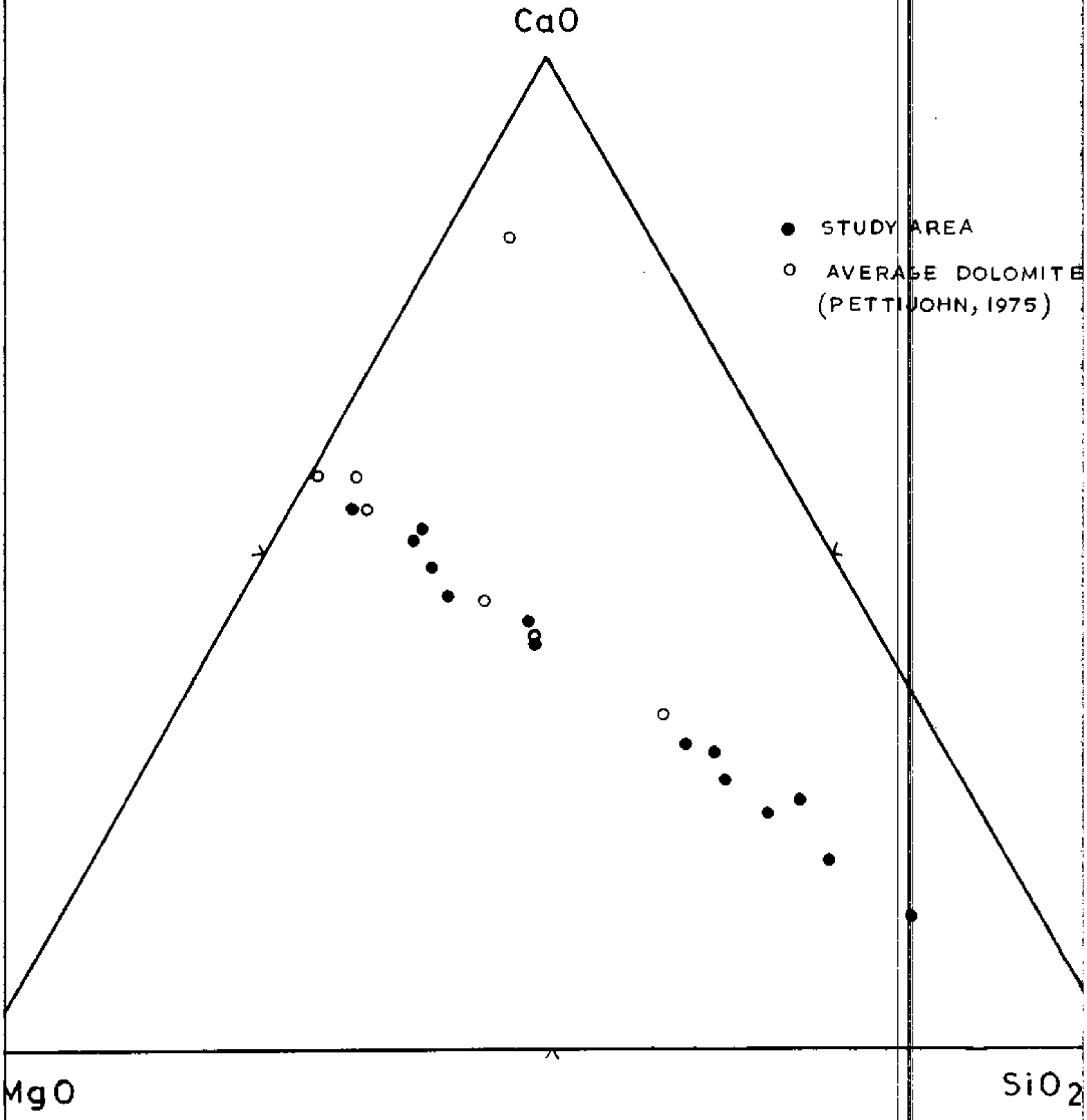


Table VII.2 Values of $CaO-MgO-SiO_2$ for Triangular diagram

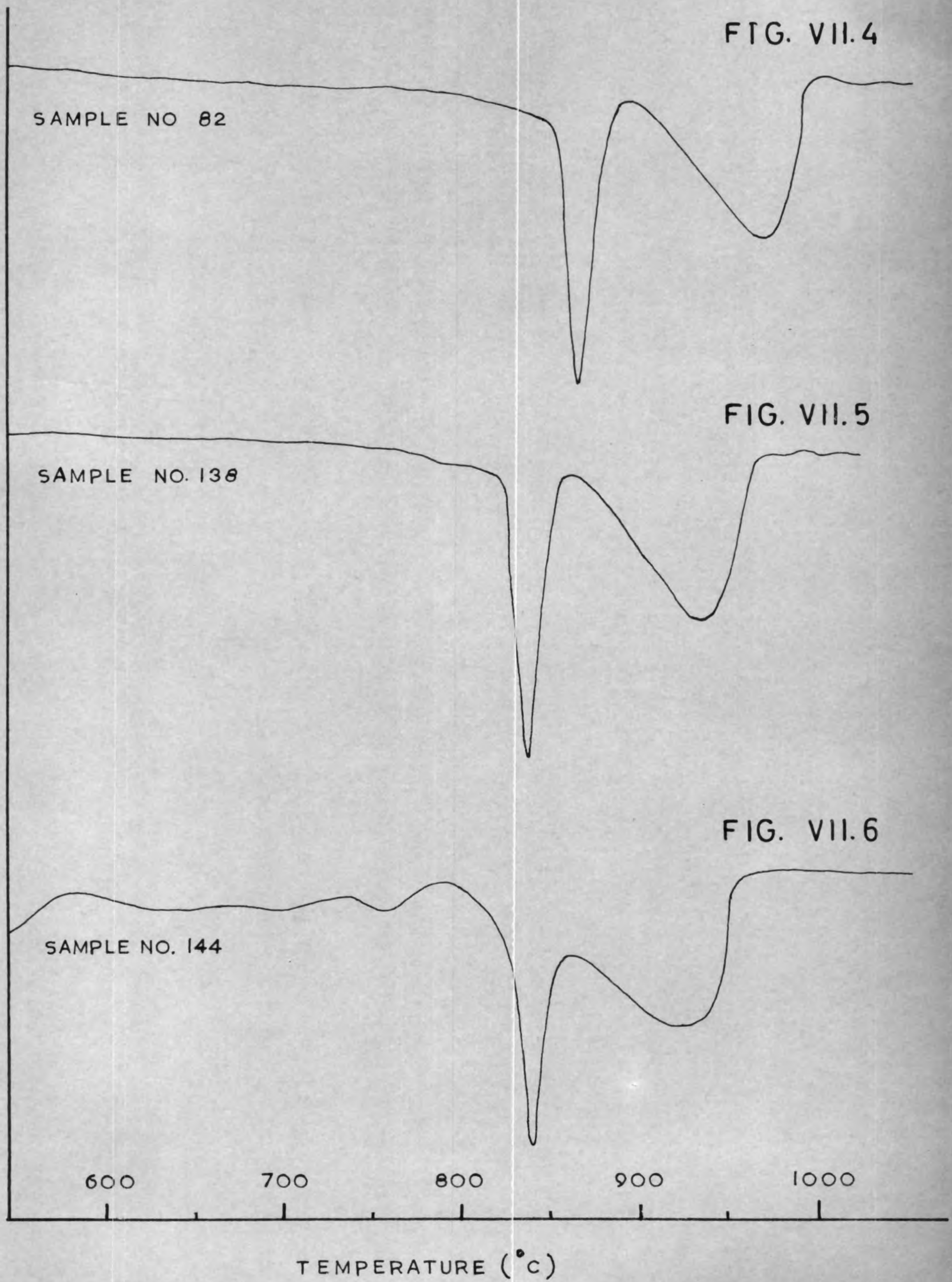
Sample No.	CaO	MgO	SiO_2
26	27.42	20.64	51.94
62	29.83	20.10	50.06
77	54.90	40.12	4.99
82	33.65	22.89	43.47
105	13.37	10.51	76.12
116	48.70	36.50	14.80
1388	42.12	30.45	27.43
144	46.12	35.70	18.18
172	53.40	35.21	11.39
188C	24.94	14.64	60.42
206	42.40	29.90	27.70
207	51.95	36.12	11.92
210	43.53	30.26	26.21
219	19.44	14.80	65.76
246	31.13	22.46	46.41
283	23.86	18.23	57.91

insolubles; as the MgO percentage increases, the insolubles decrease. All the dolomite rocks that are chemically analysed show that they are almost exclusively made up of the mineral dolomite, and calcite if present, constitutes a very little proportion. Two samples (Sample No.121 & 127) which were analysed under X-Ray (Fig. VII.2,3) show that they are exclusively made up of dolomite and quartz without calcite. The D. T. A. curves of five samples (Sample No. 82, 138, 144, 207 & 210) also give two endothermic peaks of dolomite mineral (Fig. VII.4, 5, 6, 7 & 8). The theoretical calculation of the different carbonate minerals from the chemical data (Table VII.3) shows that the rocks consist of more than 95 % of mineral dolomite. The extra CaO and MgO perhaps are present as solid solution in dolomite mineral since no calcite and magnesite minerals are found in these rocks. The Ca/Mg ratio varies from 1.51 to 1.80 with an exception of 2.02 (Table VII.3). The Ca/Mg ratio of a pure dolomite is 1.648. From the above observations it is clear that the carbonate rocks of Kali Gandaki area are precisely dolomite rock or dolostone.

CLASSIFICATION

Many authors have attempted to classify the dolomite rocks on the basis of the chemical analysis. Frolova (1959, P.35, cf. Bissel & Chilingar, 1967) attempted to classify the

D T A CURVES OF DOLOMITE



D T A CURVES OF DOLOMITE

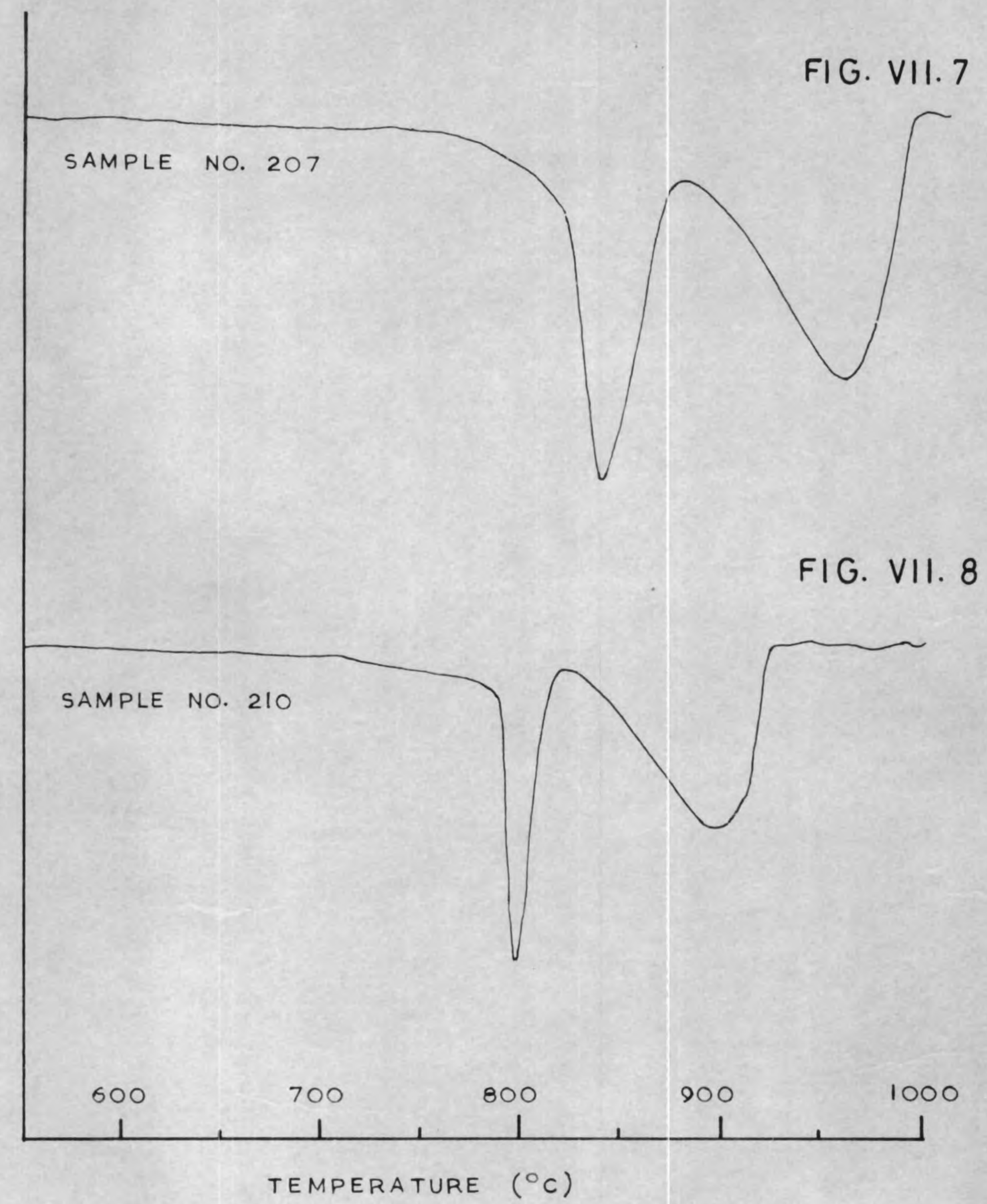


Table VII.3 Theoretical calculations of different carbonate minerals from the chemical data

Sample No.	Dolomite %	Calcite %	Magnesite %	CaO/MgO	Ca/Mg
26	97.93	--	2.07	1.33	1.57
62	96.48	3.52	-	1.48	1.76
77	99.28	-	0.72	1.37	1.62
82	96.99	3.01	-	1.47	1.74
105	95.94	-	4.06	1.27	1.51
116	98.12	-	1.38	1.33	1.58
138B	99.76	-	0.23	1.38	1.64
144	96.63	-	3.37	1.29	1.53
172	95.31	4.69	-	1.52	1.80
188C	89.10	10.89	-	1.70	2.02
206	98.92	1.08	-	1.42	1.68
207	98.17	1.83	-	1.44	1.70
210	98.17	1.83	-	1.44	1.70
219	97.41	-	2.59	1.31	1.56
246	99.85	-	0.14	1.39	1.64
283	97.22	-	2.78	1.31	1.55

dolomite-magnesite and limestone on the basis of CaO/MgO ratio and percentage of dolomite-calcite and magnesite minerals.

According to the classification of Frolova (1959), the rocks of the present study area could be classified into the following categories:

Sample No.	CaO/MgO ratio	Name
26, 77, 105, 116, 138B, 144, 219, 246, 283	1.31 - 1.39	Very slightly magnesian dolomite
62, 82, 206, 207, 210	1.42 - 1.48	Dolomite
172, 188C	1.52 - 1.70	Slightly calcitic dolomite.

Chilingar (1957a, cf. Bissel & Chilingar, 1967) also proposed a classification of dolomite on the basis of Ca/Mg weight ratios. He grouped the dolomite rocks into the following categories:

Name	Ca/Mg ratio
Magnesian dolomite	1.0 - 1.5
Dolomite	1.5 - 1.7
Slightly calcitic dolomite	1.7 - 2.0
Calcitic dolomite	2.0 - 3.5

Thus, following Chilingar's classification, the dolomite rocks of the Kali Gandaki valley falls into the following groups :

Sample No.	Ca/Mg ratio	Name
26, 77, 105, 116, 138B 206, 207, 210, 219, 246, 283.	1.51 - 1.70	Dolomite
62, 82, 172, 188C	1.74 - 2.02	Slightly calcitic dolomite.

Thus, following the classification of Frolova (1959), dolomites of the study area fall into three groups, viz., (i) very slightly magnesian dolomite, (ii) dolomite and (iii) slightly calcitic dolomite. Out of these, a majority of the samples analysed fall into the very slightly magnesian dolomite group, and only two samples fall within the slightly calcitic dolomite group. But according to the classification of Chilingar (1957a), all the dolomite rocks of the area can be classified into two groups only- dolomites and slightly calcitic dolomites. According to this classification, essentially almost all the dolomitic rocks fall into dolomite group except four, which are slightly calcitic dolomite.

On the basis of crystallirity, high degree of alteration and low degree of alteration, Bissel & Chilingar (1967, P.119) proposed a new classification of dolomite. Following their classification, majority of the dolomitic rocks of the study area could be grouped as Aphanic. They are also termed as micritic dolomite or dolomicrite and may be either chemical or mechanical in origin. According to Folk (1959), micrites (lime mud) are those limestones which consist of microcrystalline calcite. Dolomicrite or micritic dolomite is the dolomite mud in the similar sense of micrites. Leighton & Pendexter (1962, cf. Bissel & Chilingar, 1967) defined the micritic material as that consisting of particles less than approximately 0.03 mm in diameter. But Bissel and Chilingar proposed the term micrite to a crystalline or finely grained limestone with 0.05 mm or smaller diameter of the grains. Carozzi (1960, P.284) is of the view that aphanitic dolomites which look almost like chert under the microscope, their constituents, visible only with high magnifications, and extremely smaller globular grains, might correspond to an original precipitate.

The micritic dolomite of the present study area under investigation consists of essentially cryptocrystalline dolomite in which the individual crystals are indistinguishable under ordinary microscope magnification. Occasionally, they show laminated structures. Sometimes, replacement of dolomite by quartz forming islands of quartz mosaic in dolomicrites are observed. Recrystallization is not widespread. Normally no other diagenetic changes are noticed. However, the dolomitic rocks have been quite often found to be traversed by epidiagenetic quartz veins.

INTRACLASTIC DOLOMITE

Though the main bulk of these thick sequences of dolomites of Kali Gandaki valley comprise the dolomicrites, the occasional lenses of intraclastic dolomite that occur within them have been found to be of considerable significance. Here, the present author has attempted to give an account of the petrography, origin and palaeoenvironmental significance of these intraclastic layers.

Petrography

Following Folk's (1959) classification, the intraclast bearing rocks of the study area have been designated as intraclastic dolomite, since the intraclasts which are essentially made up of very fine-grained dolomite form more than 25 % of the rock by volume. The dolomitic nature of the rock has been confirmed by chemical analyses, staining, and D.T.A. studies. These rocks are composed of following allochemical and orthochemical constituents.

Allochemical Constituents

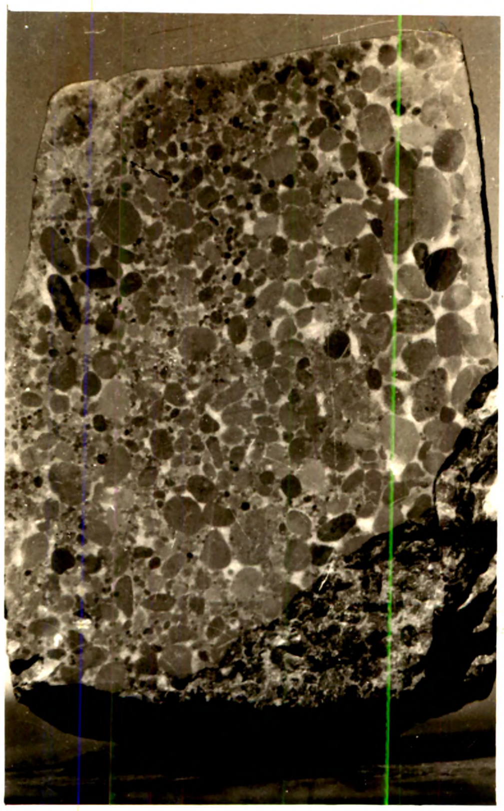
The allochems (Folk, 1959) are mainly (a) intraclasts (b) oolites and (c) peloids.

Intraclasts The term 'intraclast' was introduced by Folk (1959, P.4) to describe "fragments of contemporaneous, usually weakly consolidated carbonate sediments that have been eroded from adjoining parts of the sea-bottom and redeposited to form a new sediment."

The intraclasts of the study area are composed of microcrystalline dolomite. The sizes of these intraclasts vary greatly, ranging from 0.2 to 1 mm and in exceptional cases over 1 mm. Occasionally, very well sorted and graded nature of the intraclasts are also observed. But usually, the rock is moderately sorted. These intraclasts are mostly subrounded to rounded (Plate VII.1A), but, occasionally, slab-like, angular fragments of dolomites are also present (Plate VII.1B). The shape of the intraclasts varies from spherical, ovoidal to discoidal. It may be mentioned here that the intraclasts generally occur as very well rounded to sub-rounded and less commonly angular to sub-angular (Folk, 1959, P.5). It mainly depends upon the prolongation of the wave action, wave energy and the size of the intraclasts. If the rock from which the intraclasts are derived is well cemented before

Plate VII.1A A specimen of intraclastic dolomite with rounded to sub-rounded intraclasts.
Location: About 0.5 km SW of Phoksing (x 1.5).

Plate VII.1B A specimen of intraclastic dolomite with angular to sub-rounded intraclasts.
Location: About 1 km NE of Sakuni (Approx. natural size).



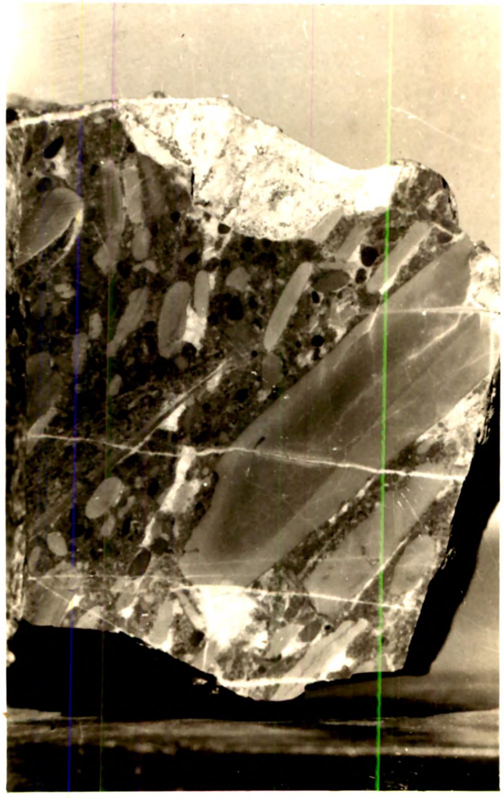


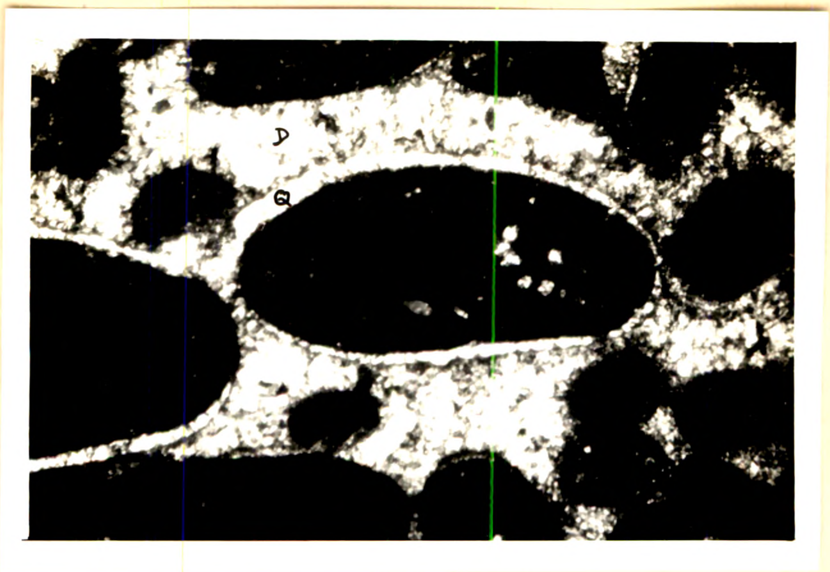
Plate VII.2A Photomicrograph of intraclastic dolomite (Phoksing Dolomite) showing authigenic development of quartz (Q) around the intraclasts.cementing material is crystalline dolomite (D) (crossed nicols, x 50).

Plate VII.2B An intraclast showing depositional laminae of the original rock. (crossed nicols, x 50).

reworking, a prolonged action of strong waves and currents will make them well rounded. Therefore, the well rounded grains in these rocks do not necessarily indicate long distance transportation and thus do not imply a non-intraclastic nature to them. The restricted composition of the fragments in these rocks further support its intraclastic nature (Pettijohn, 1975, P.185).

Authigenic development of silica around the intraclasts forming rims are common (Plate VII.2A). The quartz occupying such rings is fibrous in nature. When a polished surface of the rock is subjected to etching for 3 to 4 minutes with dilute hydrochloric acid (10 %), the rock shows numerous depressions occupied by the intraclasts while the unaffected silica forms rims around them.

The intraclasts are usually devoid of any internal structures. In some fragments, however, parallel depositional laminae are clearly discernible (Plate VII.2B). A partial to complete recrystallization of some of the intraclasts is also noticed (Plate VII.3A). In some cases the micro-quartz veins and dolomite veins cut across the intraclasts often displacing them, and grade into the surrounding matrix (Plate VII.3B). Evidently, these veins are secondary (epidiagenetic). Occasionally, the intraclasts are stretched and show preferred orientation, which is possibly due to the tectonic deformation.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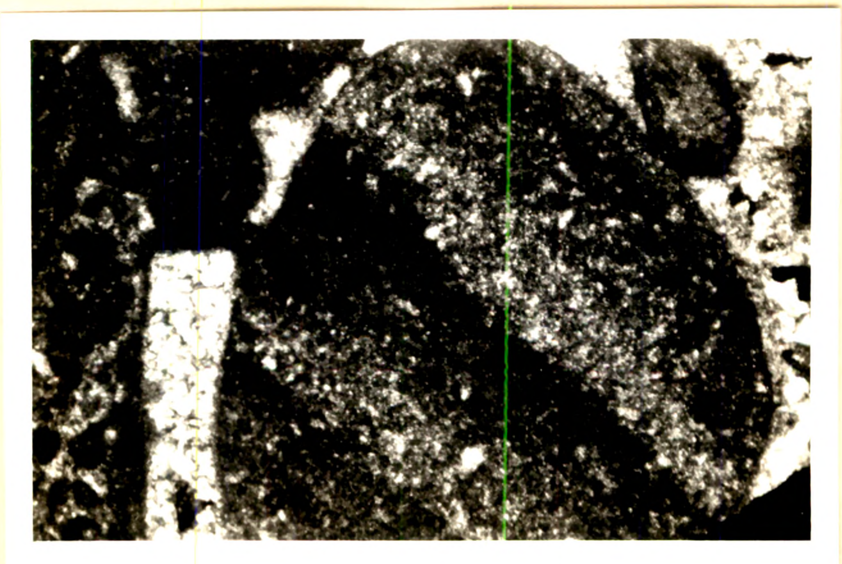
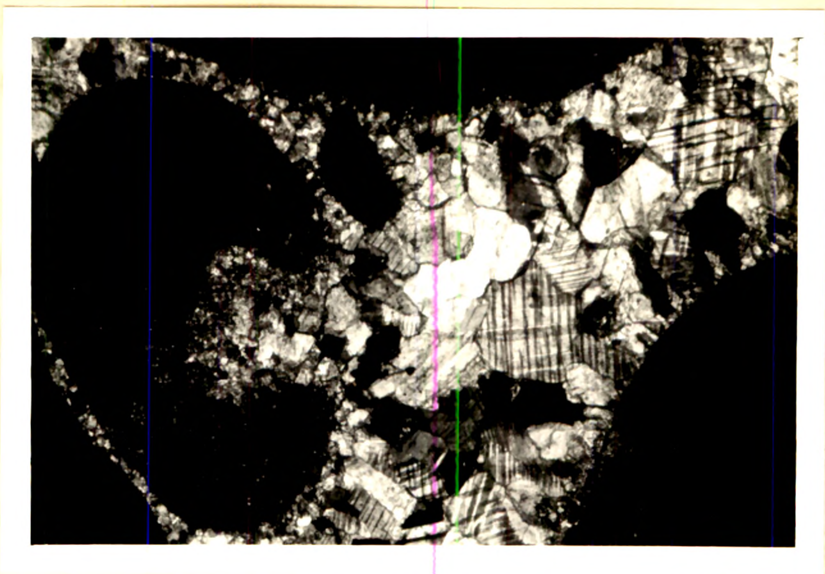
Q





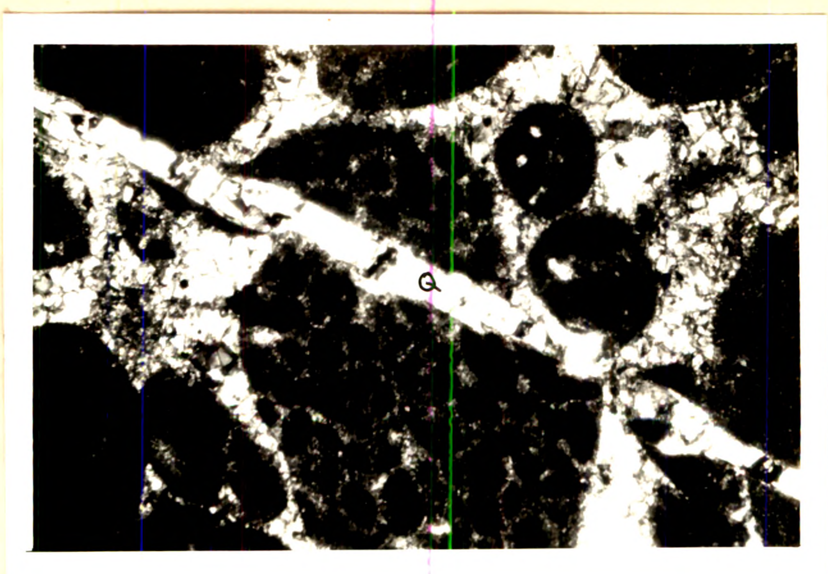
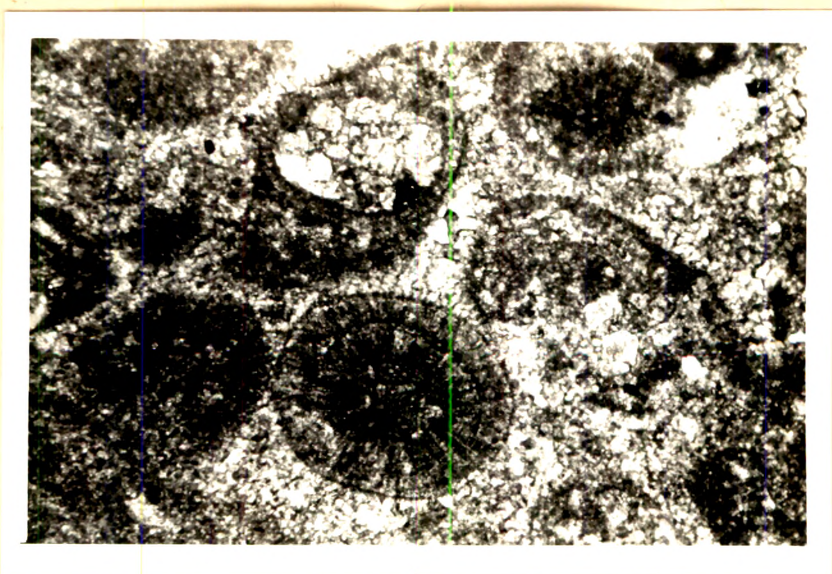

Q

Plate VII.4A Photomicrograph of intraclastic dolomite with oolites. Note the concentric and radial structures in the oolite. A partial recrystallization of oolites is conspicuous (crossed nicols, x 85).

Plate VII.4B Photomicrograph of intraclastic dolomite with superficial oolites (crossed nicols, x 75).

<u>**Oolites**</u> Oolites are next in abundance to intraclasts and these show concentric rings as well as radiating structures. Oolites having both concentric and radiating structures are not uncommon (Plate VII.4A). Commonly, size of the oolites ranges from 0.15 to 0.5 mm. The oolites are usually spherical to sub-spherical and sometimes ovoidal. In some sections, superficial oolites (Plate VII.4B) dominate over the true oolites. Here, a large nucleus made up of dolomicrite is surrounded by a relatively thin oolitic coating. The presence of broken oolites (Plate VII.5A) and intraclasts made up of composite oolites, is of considerable palaeoenvironmental significance. Recrystallization of oolites is common, but invariably they retain their original morphological outline to some extent. As the size of the majority of oolites is smaller than the intraclasts, they mostly occupy the intergranular spaces between intraclasts.

<u>Peloids</u> Peloids (Bathurst, 1971, P.84) are also quite common among the allochems. They range in size from 0.1 to 0.3 mm in diameter. They are small, spherical to ellipsoidal, ovoid bodies devoid of internal structures. In contrast to intraclasts, the peloids are smaller in size and comparatively better rounded. These too, like oolites,occupy the intergranular spaces of the intraclasts. It is presumed here that the peloids have resulted due to gas bubbling or by 'algal budding'



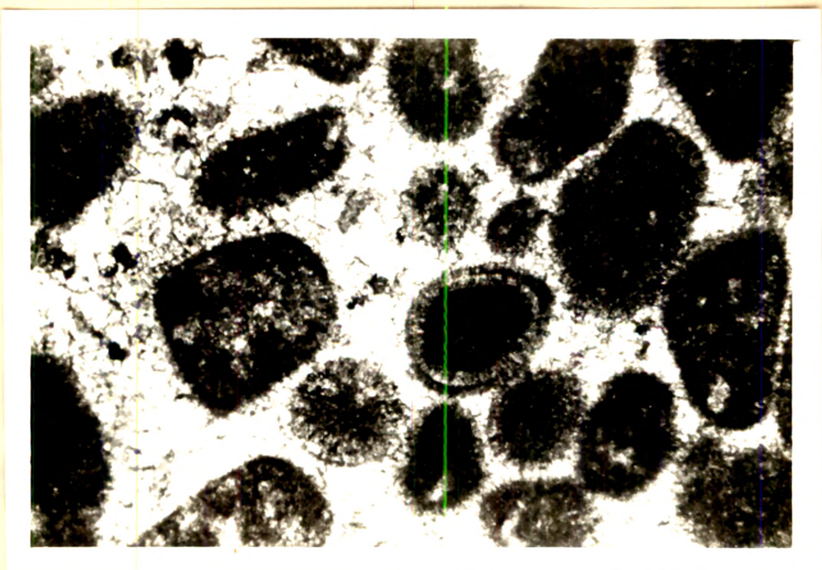
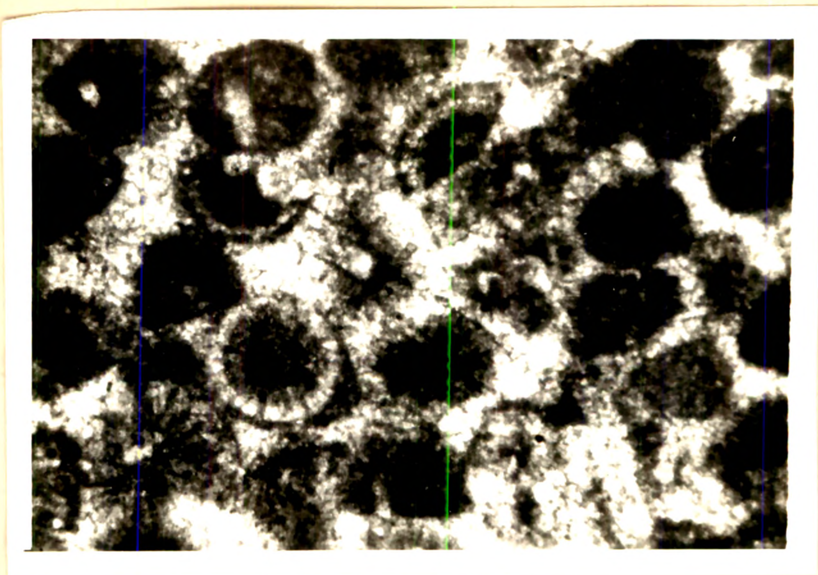
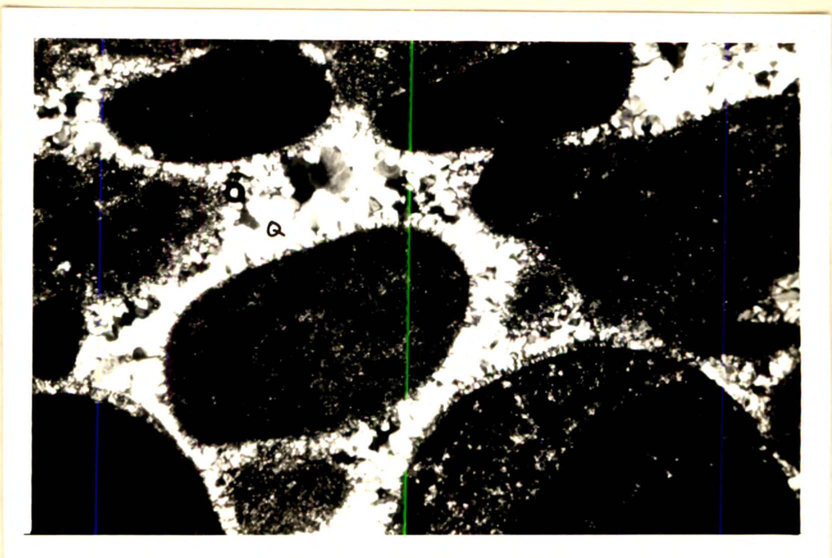


Plate VII.5A Photomicrograph of intraclastic dolomite showing broken oolites. (crossed nicols, x 75).

Plate VII.5B Photomicrograph of intraclastic dolomite cemented by fine grained quartz (crossed nicols, x 50).




a

(Bissel and Chilingar, 1967, P. 163). The prolific development of stromatolites indicating luxuriant growth of algae in the dolomite rock, favours the above postulation.

Among the terrigenous material, quartz is the most common constituent and it is more abundant in the upper horizon of the dolomite sequence. The quartz grains vary in size from 0.2 to 1 mm in diameter and are subangular to subrounded. They do not show any authigenic growth.

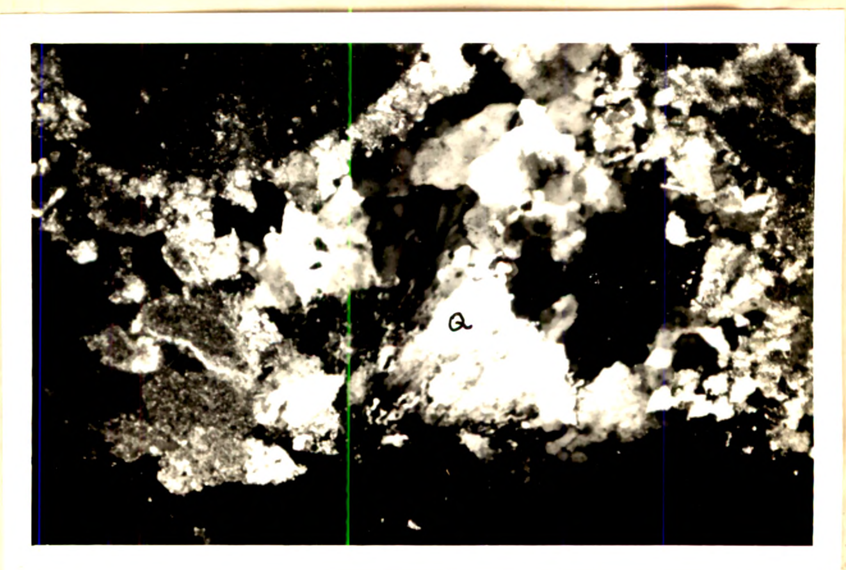
Orthochemical Constituents

The cementing material filled in the interstitial pores between the intraclasts and other allochems is usually crystalline dolomite (Plate VII.3A). The larger voids filled with sparry dolomite show coarsegrained mosaic texture. Syntaxial overgrowths (Pettijohn et al., 1973, P.339) around the intraclasts are quite commonly observed. It is noted in most of the sections that an overgrowth starts as tiny crystals on the immediate substrata and as the crystals move away, they get progressively larger in size. Such a phenomenon is due to either minor fluctuations in individual crystal growth rates or due to a slowing down of crystal growth with pore space becoming progressively filled and permeability reduced (Pettijohn et al., 1973). Occasionally, the cementing material is either wholly fine-grained quartz (Plate VII.5B) or mixture of quartz and crystalline dolomite. Staining process also confirms the crystalline cement to be dolomitic type.

Replacement of dolomite by finegrained silica is very common. As described earlier, some of the intraclasts are rimmed partially or wholly by microcrystalline silica and seem to be of diagenetic origin. The replacement of this nature is due to relatively easy accessibility of the silica solution along the grain boundary. Patchy replacement of dolomite by silica is also common. This fact is clearly indicated by the gradational boundary between finegrained dolomite and silica and the presence of islands of dolomite crystals within microcrystalline silica (~~Plate VII.6A~~). The source of the silica must be the sea water. When the sea water is supersaturated with silica and appropriate pH conditions are obtained, silica can precipitate. The replacement of carbonate by chert will be facilitated in a lower pH value when the carbonate will be dissolved and side by side silica precipitation occurs (Walker, 1962). The spherulites showing radially arranged "flamboyant quartz" (Plate VII.6) which are occurring in these intraclastic rocks are also due to selective silica replacement of the dolomitic matrix (Kharkwal and Bagati, 1974).

Plate VII.6 Photomicrograph of intraclastic dolomite with flamboyant quartz (Q) (crossed nicols, x 50).

x

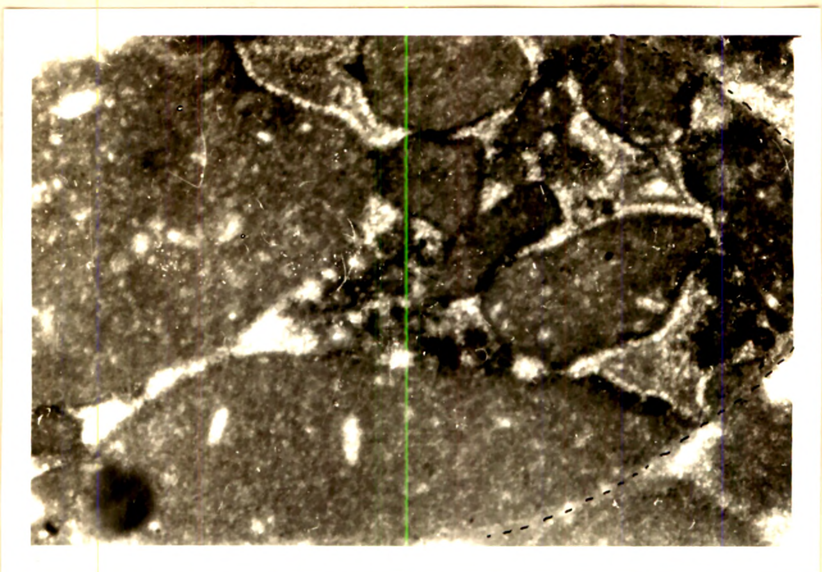


ORIGIN AND PALAEOENVIRONMENTAL SIGNIFICANCE

There has been some controversy regarding the origin of intraclasts and the formation of intraclastic rocks. Two theories have been put forth. According to the first theory (Folk, 1959 ; Bissel and Chilingar, 1967), the origin of the intraclasts is mainly due to reworking of contemporaneous and older finegrained carbonate rocks and the sub-squeous aggradation of these fragments. Carozzi, (1960, p.228), on the other hand, has advocated the alternative mechanism of contemporaneous aggregation process and further postulated that the intraclasts could be generated 'in situ' without reworking of previously deposited and indurated finegrained sediment.

Out of these two possibilities, the intraclasts of the study area, according to the present author, appear to have resulted due to the reworking process. The aggregation process, if at all operated, having played a minor role. The sharp, angular, slab-like fragments (Plate VII.1B) sometimes associated with these rocks could not have been resulted due to a aggregation process. They are undoubtedly produced by mechanical breakdown of the pre-existing finegrained dolomite rock. Further, the intraclasts made up of fragments of older intraclastic rock (Plate VII.7) and oolitic rock of earlier cycle, a few broken and abraded oolites (Plate VII.4B) fully support the above mode of origin.

Plate VII.7 Photomicrograph of a composite intraclast (crossed nicols, x 50).



Intraclastic dolomite reflects a characteristic environment of deposition. The origin of the intraclasts, their abrasion, transportation and ultimate deposition, exhibiting their clastic nature, require a unique and very appropriate environmental condition. On the basis of the study of stromatolitic structures, it has been shown that the dolomite rock of the study area was deposited in a warm, shallow, marine basin, ranging from intertidal to supratidal and occasionally even upto subtidal conditions.

The prolonged calm-water condition of deposition of fine-grained carbonate rock must have been interrupted because of sudden disturbances, which could be well expected in a tectonically active basin. But such conditions were brief and periodic, as could be inferred from the small extension and thickness of these intraclastic layers. Due to these tectonic disturbances the subtidal and intertidal carbonates must have been exposed to the sub-aerial conditions; and thus shrinkage cracks due to desiccation were developed. These desiccated rocks were subsequently attacked by the spring-tides and storms breaking them into small fragments which were then transported to sites of strong wave action. It was here, that the main process of abrasion and winnowing of the fragments started and continued till their final deposition in a suitable place.

Some of the intraclasts which are made up of fragments of the intraclastic rock of earlier cycle, and composite oolites derived from the earlier formed oolitic rock, indicate the unstability of the depositional basin and changes in the palaeoenvironmental conditions.

Well rounded to sub-rounded intraclasts clearly indicate their prolonged abrasion by the waves and currents before their final deposition. To withstand such a strong action of waves and currents, the pre-existing dolomicrite must have been well cemented and lithified before their reworking (Germann, 1969). Similarly the fragments of the 'first cycle' intraclastic and oolitic rocks clearly show their strong cementation and lithification, such that they resisted disintegration after continued aggradation by wave and current action. Further, the sparry dolomitic cement of these rocks typically suggests that they have been deposited in a sufficiently high-energy environment to remove the finer material. It is, however, difficult to estimate what percentage of the oolites is primary, i.e., developed in situ in that high energy agitating water and how much was derived from an earlier formed oolitic rock. Though, most of the composite and some broken oolites are derived from older or contemporaneous oolitic rocks, some superficial oolites seem to have developed in situ.

It has also been envisaged that the 'first cycle' intraclastic and oolitic rocks were deposited in a comparatively lower-energy environment, as evidenced by the presence of microcrystalline cementing material in them. The second cycle of formation of this intraclastic rock possibly indicates increase in the energy level either due to the lowering of sea-level or alternatively, upheaval of the basin or both, so as to rework the earlier formed low-energy intraclastic and oolitic rocks and the adjoining fine carbonate sediments and redeposit in a new high energy environment.

STROMATOLITES

Excellent exposures of stromatolitic structures are found occurring in the bluish-gray dolomitic rock sequence of the Kali Gandaki Valley section. An attempt has been made here, by the author, to compare and correlate them with similar structures known from the Indian Himalaya, some regions of Peninsular India and those from other parts of the world. A majority of the Nepal stromatolitic structures can be ascribed to the larger groups of Collonella and Conophytons, and these are closely comparable with the forms described from Pithoragarh and Deoban areas of the Himalayan region of India and with the stromatolitic assemblages reported from the Malmani Dolomites of South Africa.

The author has presented for the first time a detailed account of the well-preserved stromatolitic structures found in these otherwise unfossiliferous dolomitic sequence (Phoksing Dolomite). These algal structures have been mentioned in the works of Bordet et al. (1964a), Bodenhausen et al. (1964), Nadgir & Nanda (1966), Fuchs (1967), Fuchs & Frank (1970), Sharma (1975) and Ohta & Akiba (1973). But none of these workers, have given details pertaining to the systematics, age, correlation and palaeoenvironment of these stromatolites.

The distribution of carbonate rocks along with the reported occurrences of stromatolites in Lesser Himalaya of

Nepal compiled from the geological maps of Fuchs (1967) and Sharma (1975) is shown in Fig. VII.9.

Types of stromatolites and their characteristics

The stromatolitic structures are confined to the bluish-gray, massive to thickly bedded dolomite sequence, that constitutes nearly one-third of the exposed stratigraphic sequence of the Sirkang Unit. Good exposures of these rocks with well preserved stromatolites are found near Badsawot, Kulamathi, Kuplechaur, Deorali, Hardi, Lungdi, Ragmas and Karnas villages. A thick vertical section of such rocks from the base of the Kali Gandaki river (610 m) to the top of Gorlang Khoria (2172 m) is observed near Phoksing village. This dolomite sequence occasionally shows minor alternations of impure sandstones and carbonaceous slate layers in its upper stratigraphic horizons.

The following important morphological types of stromatolites are recognised :

(a) Flat laminated algal mat ;

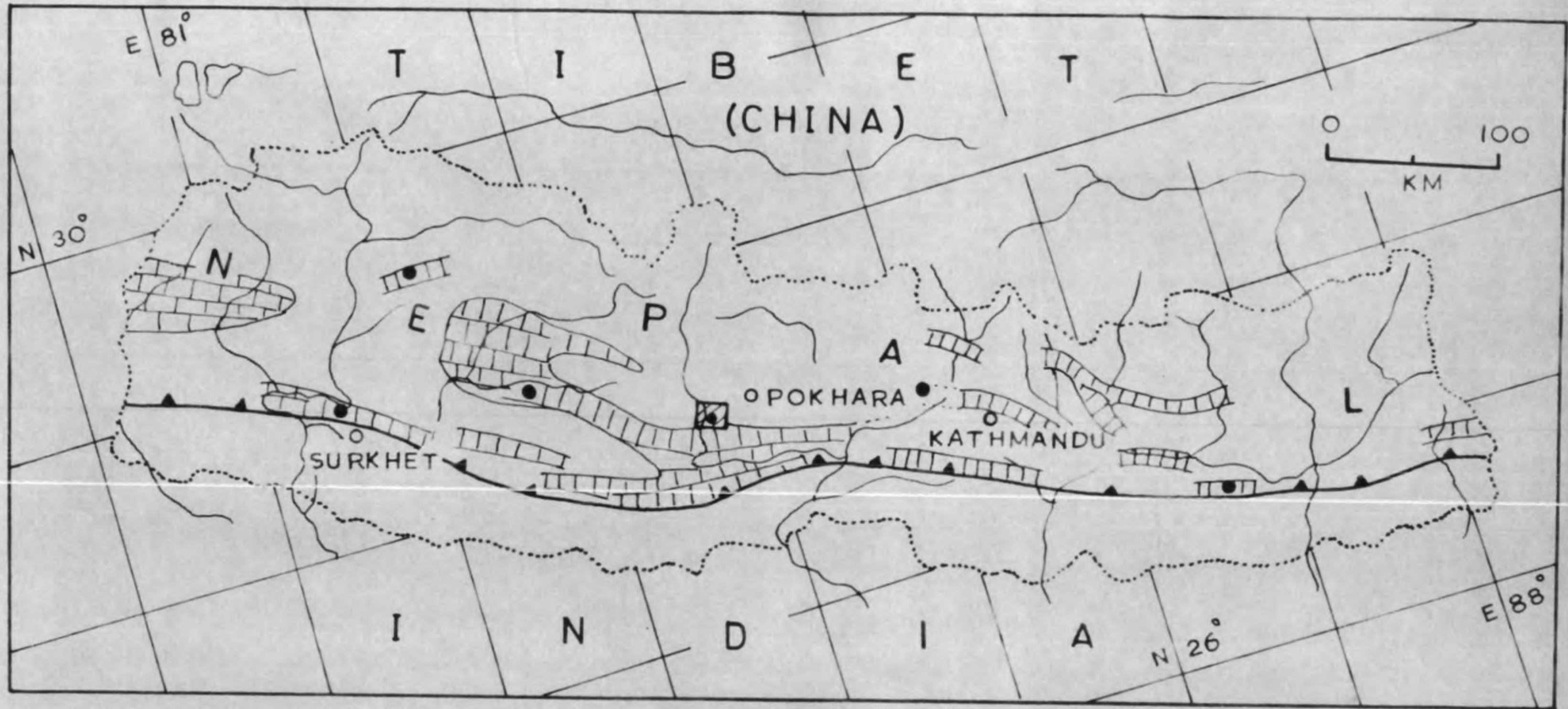
(b) Crinkled and laminated bio~~c~~hermal ;

(c) Columnar and conical and

(d) Large-scale vertically stacked domical.

DISTRIBUTION OF CARBONATE ROCKS IN LESSER HIMALAYA OF NEPAL

(AFTER SHARMA,1975. FUCHS,1967)



• LOCATIONS OF STROMATOLITE OCCURRENCE

CARBONATE ROCKS

STUDY AREA

FIG. VII.9

Flat Laminated Algal Mats

This type of stromatolite (Plate VII.8A , 8B) resembles the presentday algal mats and filamentous sheaths that are seen growing along Persiar Gulf, Bahama, Shark Bay, and California coast (Kendall and Skipwith, 1968 ; Monty, 1972 ; Logan et al, 1974 ; Horodyski and Vonder Haar, 1975). This group is widely developed throughout the dolomitic sequence. Small scale crinkled, convolute, columnar and cylindrical, steeply overfolded algal structures are sometimes found associated with this type. Solitary algal heads interspersed in the algal mats are also observed. In some instances, the cherty layers wedge out of the algal laminations.

Crinkled and Laminated

Biohermal Stromatolites

These are usually elongated bioherms of various sizes ranging from fraction of a meter to few meters in length, width and height (Plate VII.9A). Spherical heads are sometimes found associated with these structures possibly developed by rolling of the detached algal mats by the waves and currents.

Plate VII.8A Field photograph of flat laminated algal mat with conspicuous minor crinkling.

Location: Near Kuplechaur in the tributary stream section of Bachha Khola.

Plate VII.8B Field photograph of flat laminated algal mat with crinkled laminae and spherical heads.

Location: About 0.4 km south of Amrigaon along the main stream section of Bachha Khola.

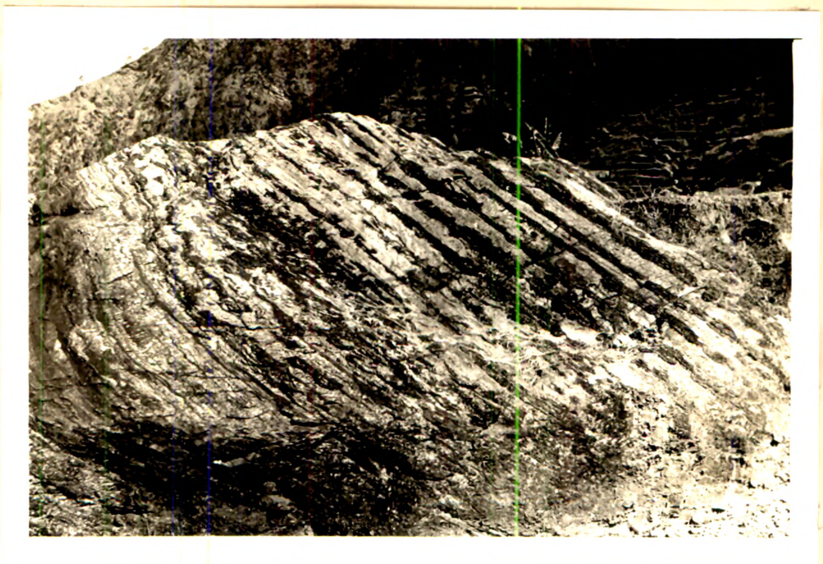
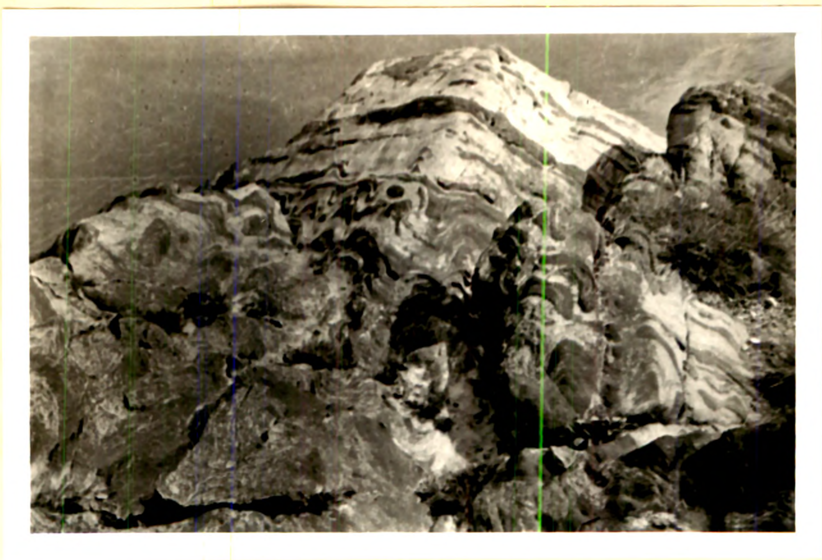


Plate VII.9A A stromatolite bioherm.

<u>Location</u>: Right bank of Karnas bridge, near Karnas. (Approx. x 1/30).

Plate VII.9B A specimen showing conical stromatolite.

<u>Location</u>: About 0.5 km SE of Derandi. (x 1.5).



Columnar and Conical Stromatolites

This type includes conical and columnar stromatolites commonly referred to Conophyton and Collenia respectively. (Plate VII.9B, 10A, 10B, 11A, 11B, 12A, 12B, 12C, Fig.10). The respective laminae of these two structures are conical and domal in vertical sections, and circular to ovoidal in planar sections. Interspaces between the adjacent columns are sometimes occupied by intraclastic and pelletal material, and also by cherty patches.

The common forms that could be recognised include Conophyton cylindricus Maslov, Collenia columnaris Fenton and Fenton, Collenia symmetrica, Fenton and Fenton, Collenia undosa Walcott and Collenia compacta.

Large-scale Vertically Stacked Domical Stromatolites

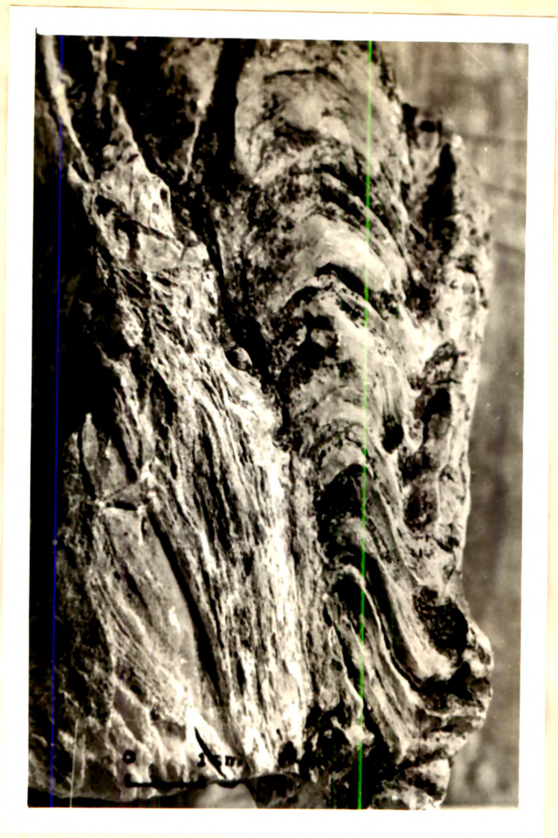
The large-scale elongated, vertically stacked domical structures encountered occasionally are quite interesting. (Plate VII.13A , 13B). These are characterised by a vertical development of stout, rounded, domical crests and prominent 'V' shaped troughs. These domical structures range upto 2 meters in height and 1 to 1.5 meters in diameter. The 'V' shaped troughs are invariably filled with dolomitic breccias,

Plate VII.10A A specimen showing conical stromatolite.

<u>Location:</u> On the left bank of the Karnas bridge. (Natural size).

Plate VII.10B A cut and polished specimen of conical stromatolite.

<u>Location</u>: Near Sakuni. (Approx. Natural size).



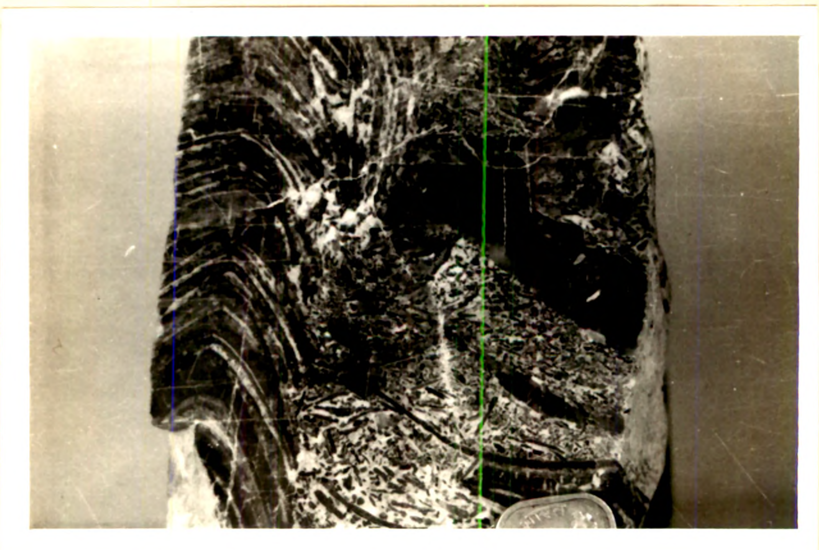


Plate VII.11A A field photograph of conical and colomnar stromatolite.

Location: Right bank of Karnas bridge near Karnas. (x 1/4).

Plate VII.11B A field photograph of columnar stromatolite.

Location: About 0.5 km NE of Pangran in the stream section. (x 1/8).

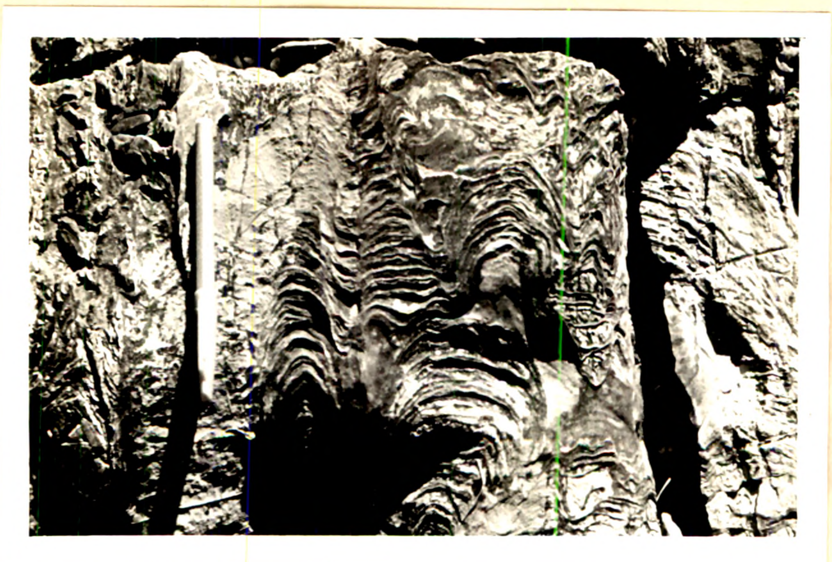


Plate VII.12A A field photograph of columnar stromatolite.
Location: About 0.6 km south of Amrigaon across Bachha Khola (x 1/8).

Plate VII.12B A cut and polished specimen of columnar stromatolite. Also, note the intraclastic material to the left of the columnar structure.
Location: Near Sakuni. (Approx. natural size).

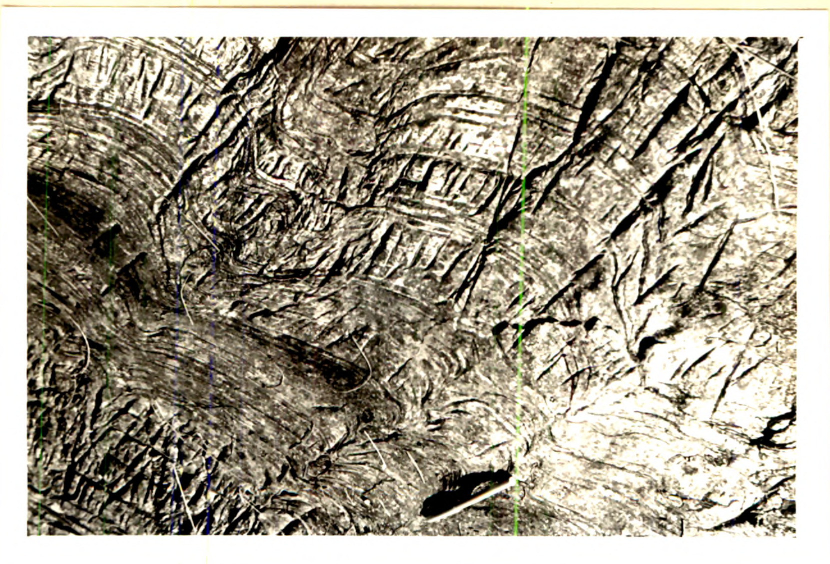


Plate VII.12C A specimen of columnar stromatolite.

Location: About 0.4 km west of Baon village, in the stream section. (Approx. natural size).

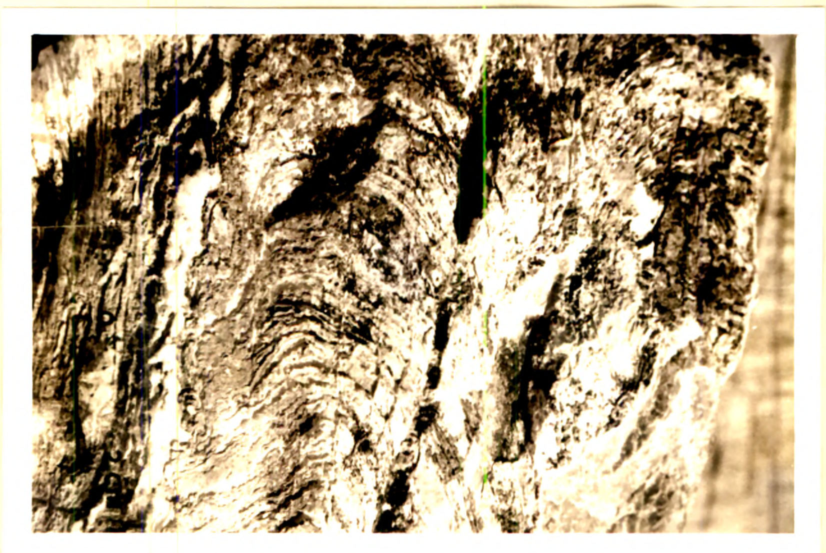


FIG. VII. 10

Columnar and conical stromatolites

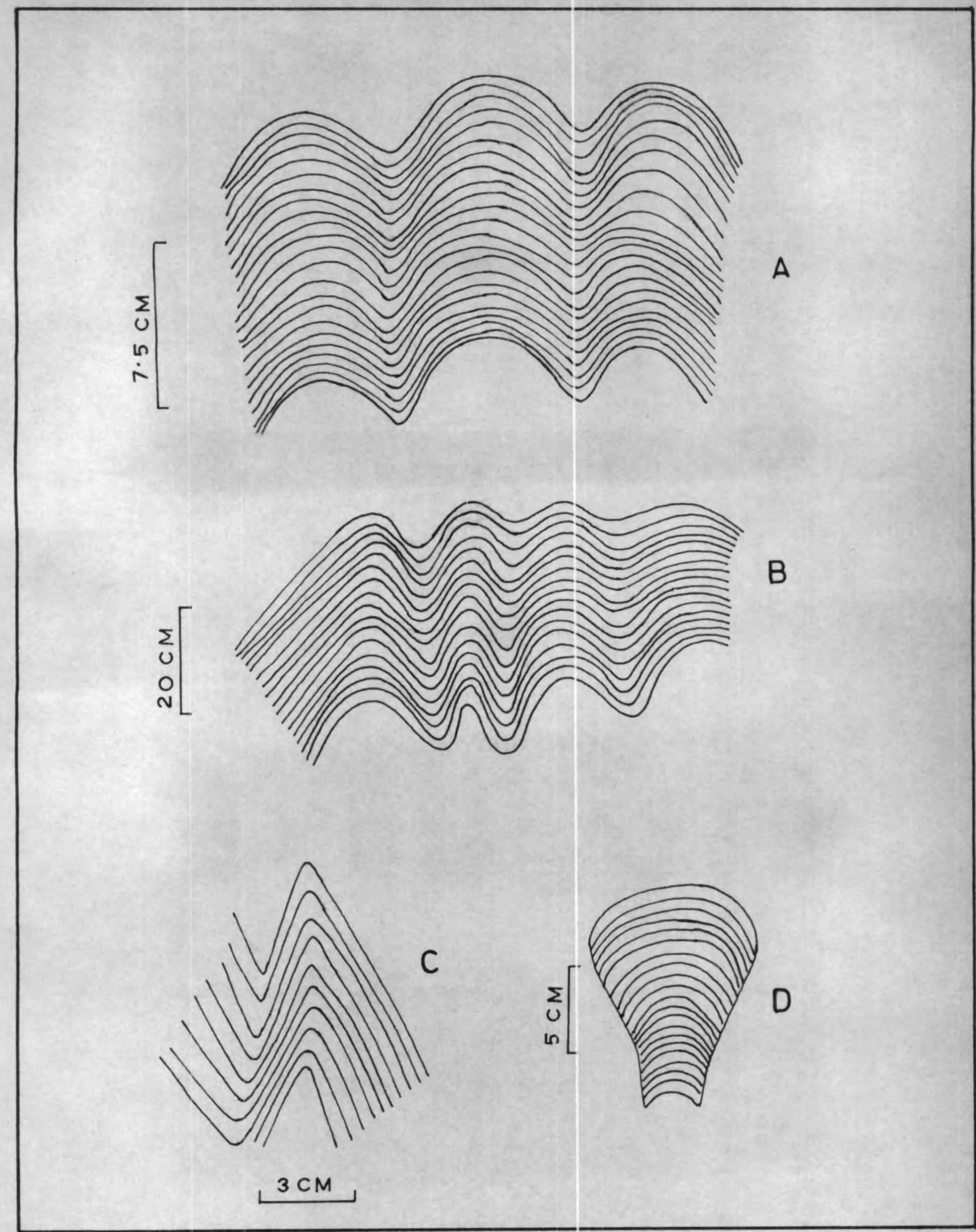


Plate VII.13A A field photograph of a large-scale domical stromatolite.

Location: Near Pathikharka village in the stream section (x 1/25).

Plate VII.13B A field photograph of large-scale domical stromatolite.

Location: Near Pathikharka village in the stream section. (x 1/9).

intraclasts and peloids. It is interesting to observe that such structures have not been reported from any other parts. of Himalaya or even from the Peninsular Indian region.

Palaeoenvironmental Significance

The outstanding contribution of Black (1933) on the laminated sediments on the Andras Island, Bahama, was a true beginning of the understanding of stromalites and their importance. Due to his pioneering work, for the first time, their environmental significance was widely acknowledged. He showed that the colonies of coccoid and filamentous algae which thrive on the intertidal and supratidal flats can trap sediment on their filaments by vertue of the sticky mucilaginous sheaths giving rise to the stromatolite. He found that more than fifteen cyanophyte species were engaged on this work.

Recently, much importance has been given on the study of the algal stromatolite on account of it being an excellent tool for the palaeo-ecological interpretations. Extensive work on the recent stromatolites has increased our knowledge on the environmental conditions of the formation of stromatolites.(Black,1933; Logan,1961; Logan et al. 1964; Monty,1967; Kendal & Skipwith, 1968; Gebelein,1969; Neumann et al.,1970; Davies,1970; Gebelein,1976; Playford et al.,1976; Eggleston et al., 1976; Water, 1976).

Very often the correlation of the environmental conditions of formation of Recent stromatolites with the ancient ones is questioned. Playford et al. (1970, P.408) has opined that there was considerable danger of accepting incompletely known modern environments as definitive guides to the past. According to him, the nature of ancient environments should be deduced from envidences in the ancient rocks themselves, without the mandatory need for modern analogues, especially as ancient environments need have no modern counterpart. Similarly Pannella (1976, P.676) cautioned that as we are living in an unusual geologic-climatic conditions, extrapolations from modern analogues to Phanerozoic stromatolites are dangerous. From modern analogues to their Precambrian ancesters, however, there is a 'quantum jump' because of the time involved and of the biological and geological evolution of our planet.

Gebelein (1976, P.514) discussed in detail about the feasibility of application of the recent model to the ancient stromatolites and has come to the conclusion that "a great deal of recent data can still be applied to the interpretation of Precambrian stromatolite forms and microstructures, as long as we keep in mind that formation occurred in the subtidal zone. Blue green algal association function in much the same way, whether they are intertidal or subtidal (Neumann et al. 1970)."

His observations on physical, chemical and biological evolution of the earth, substantiates his views (P.500).From the beginning of the early Proterozoic, or the Proterozoic of Cloud (2.6 to 2 b.y.), the physical character of the earth's surface takes on a nearly "modern aspect". Widespread carbonate sediments are known from this Era, including shallow marine carbonate deposits, as well as continental deposits. He concludes that there were favourable physical environments for development and proliferation of stromatolites and stromatolite biotas and therefore, the geographic mechanisms controlling distribution of stromatolite biota, as studied in Recent (Gebelein 1974), should be applicable to rocks younger than 2.6 b.y. He cited the example of Slave province rocks of 2 b.y. age where all available slopes, platform margins and platform-interior environments were colonized by stromatolite forming biotas. He also pointed out that at least since 2 b.y., it is unlikely that major changes in seawater chemistry have occurred. Also, the carbonate equilibria have not changed markedly since at least the beginning of the Proterozoic.

It has been amply shown by many workers that development of stromatolite forms and stromatolite-building biotas reached a peak in the early to middle Proterozoic and rapid decline in the abundance and diversity of stromatolites in the latest stage of Proterozoic ($<$ 800 my). This change, according to Gebelein (1976) is due to the development of metaphytes and metazones. Prior to this event, blue green algae and stromatolites occupied a much broader range of environment than they did during the Palaeozoic and younger Eras. Thus Late Proterozoic and Phanerozoic stromatolites became confined more and more to environments where the activity of metazoans was restricted or eliminated. The inability of invertebrates to survive hypersaline conditions, as in Shark Bay, left this environment open for stromatolite building. Gebelein also believes that most of the ancient stromatolites are subtidal as there are rare evidences of desiccation in Proterozoic and older stromatolites. The size of some of the Proterozoic columnar stromatolites necessitates a subtidal origin of these forms. The lateral continuity of individual stromatolite beds or microstructures are believed to represent a uniform, therefore subtidal environment.

Morphology and Environmental Conditions of Formation

Most of the authors have arrived at conclusion on the morphogenesis of stromatolites that the morphology of stromatolites depends both on the taxonomic composition of the stromatolite-forming algae and on the prevailing environment. Serebryakov (1976) has observed that inspite of variability of the morphology under the influence of environments, due to biotic control over the morphology of stromatolites each Riphean subdivision has specific, unrepeated assemblages of structures. He also suggested that it is the fluctuation of depth that seems to be the main cause responsible for the change in the morphology of the stromatolites. He gives the example that the replacement of columnar layered stromatolites by stratiform stromatolites in the sedimentary rhythmes of the Omakhta suit is likely to have been associated with the gradual deepening of the basin. He also points out that stromatolites of various morphologies but identical microstructures formed as a result of the life activity of a single community or species of algae. Bathurst (1971, P.230) opines that the dynamic balance between organic growth and sediment accumulation is influenced by numerous environmental factors to yield stromatolites or mats, with a varied range of morphologies.

Most stromatolites, fossils and Recent, according to Golubic (1976) are interpreted as organosedimentary structures formed by sediment trapping and binding and/or mineral precipitation within prostrate microbial communities termed algal mats. Also, Walter (1976) prefers the definition of stromatolites as organosedimentary structures produced by sediment trapping, binding and/or precipitation as a result of the growth and metabolic activity of micro-organisms, principally cyanophytes. According to Walter (1976), stromatolites can form in almost any free-standing body of water, providing the following conditions are met :

1. the environment is suitable for the growth of appropriate micro-organisms,

2. the rate of growth of the constructing micro-organism exceeds their rate of consumption by other organism,

3. the rate of sedimentation is sufficient to produce preservable structure but is not so great as to prevent colonization by micro-organisms and

4. the stromatolite acrete faster than they can be destroyed by boring and burrowing organisms and erosive and other mechanical and chemical forces.

Brock (1976) has described the environmental microbiology of living stromatolites and discussed the environmental limits and tolerances of the blue-green algae (cyanophytes), the principle organism that forms the stromatolites, and associated bacteria. Golubic (1976) also described in detail the organisms that build up stromatolites. According to him the presence of micro-organisms within a Recent or fossil stromatolite does not necessarily imply casual relationship with the genesis of the structure (P. 115). With respect to their function, micro-organisms may contribute to the construction of the structure, be passively present, or contribute to its destruction. Stromatolites-building micro-organisms colonize both hard and loose substrates preparing an extraordinary broad spectrum of benthonic environments for potential stromatolite construction. The explanation for the limited occurrence of Recent stromatolites probably includes competition for space by eucaryotic algae, aquatic plants or reef building organisms and competition for mineral support by various skeleton - producing eucaryotes. The distribution of stromatolite-building micro-organisms is largely determined by ecological factors. The same or very similar taxa may have a cosmopolitan distribution. However, subtle differences in climate and local ecology are frecuently responsible for significant changes in microbial composition, their interaction within a community, and in the resulting stromatolite morphology.

The conservative view that stromatolites are strictly intertidal and supratidal phenomena was accepted by many workers. However, in recent years there has been increasing evidences to show that many ancient and modern stromatolites are subtidal (Playford et al.,1976, P.396). They have shown that the living stromatolites at Hamelin Pool are widely developed in subtidal as well as intertidal environments. They extend from depths at least 3.5 meters below sea level to about high-water-spring tidal level. Gebelein (1976) also believes that most of the ancient stromatolites are subtidal. Monty (1973) has shown that bacterial stromatolites are growing today in abyssal water depths.

Pannella (1976, P.674) has shown that light stimulation, by controlling metabolism, plays an essential role in the growth of stromatolites. It has been experimentally proved that stromatolites form with a daily frequency because of light stimulation of algae or bacteria. The stromatolites consisting of alternate organic rich laminae (deposited during the day) and inorganic rich laminae (deposited at night), suggest daily growth is a basic feature of some stromatolites. Gebelein (1969) described daily layers of about 1 mm thick from subtidal algal oncolites from Bermuda and attributed them to the day-night algal growth cycle. But the supratidal laminations are not daily phenomena, as supratidal algal mats grow only during flooding which depend on many factors.

Pannella (1976, P. 676) has shown that ideal growth sequence can only form in a subtidal environment, where the light-dark cycle is still effective and where physical disruption is less likely, provided where metazoan life is impossible. He gives the following conditions for the formation of ideal sequences:

1. be aqueous, quiet and with some physico-chemical parameters oscillating regularly and periodically with daily fixed frequencies,

2. be affected by tides but not subjected to strong storm waves,

3. be populated by algae or bacteria with diurnal growth and which causes precipitation of a preservable layer,

4. be lacking in other biological systems which cause disruption.

DEPOSITIONAL FACIES AND PALAEOENVIRONMENTS OF KALI GANDAKI STROMATOLITES

Truswell & Eriksson (1973) ; Gebelein (1974,1976); Hoffman (1974), Logan et al. (1974), Eriksson & Truswell (1974) and Eriksson (1977) have all regarded the algal stromatolite structures as a useful tool in interpreting the proterozoic palaeoenvironments. The present author has followed Eriksson's (1977) depositional model of Malmani Dolomite of South Africa and has interpreted the Nepal structures accordingly. Considering the morphological features and the distribution of the stromatolites in the stratigraphic sequence, the following three sub-environmental facies have been worked out : (i) flat laminated algal mat stromatolitic facies , (ii) crinkled biohermal facies and (iii) oversteepened large scale domical stromatolitic facies.

Flat Laminated Algal Mat Stromatolitic Facies

This facies is well developed throughout the dolomitic sequence. Eriksson (1977) considered such flat laminated algal mat structures as characteristic of a low energy tidal-flat environments and carbonate precipitating lakes where the carbonate muds are trapped and bound by the algal microbiota and the regular geometry of the resulting stromatolitic structures is mainly due to its biological control. Horodyski & Vonder Haar (1975) have reported similar well preserved mats from the Laguna Mormana, a hypersaline closed lagoonal complex on the Pacific Coast of Baja California, Mexico. The formation of these structures in Nepal are thus suggestive of their development in some low energy tidal-flat, semiprotected hypersaline lagoonal environment.

Crinkled Laminated Biohermal Stromatolitic Facies

Next in abundance to the flat laminated facies are the crinkled and laminated biohermal stromatolitic facies in which many of the Conophyton and Collenia type structures are developed. Monty (1972), Gebelein (1969) and Walter et al. (1974) have studied such cuspate or crinkled elongated bioherms from the Holocene environment and have remarked that such forms are biologically controlled and thrive in an intertidal to subtidal environment . Similar environments with moderate to high energy is therefore be envisaged for this facies in Nepal. The frequent association of intraclastic material also points to a some what higheør energy environment.

Over-steepened Large-scale Domical Stromatolitic Facies

Oversteepened large-scale domical stromatolit~~i~~es are more characteristically developed in the lower part of the stratigraphic sequence. These structures show great similarity with the forms reported by Eriksson (1977) from South Africa, and according to him, these Proterozoic forms are comparable to the modern large-scale structures known from the semi-protected tidal-flat areas of Shark Bay.

The huge thickness of the bluish-gray dolomite with persistent development of various stromatolitic facies indicate a continuously slowly subsiding basin where for a long time the tidal-flat environments prevailed. The thin alternations of impure sandstones and carbonaceous slaty layers developed in upper part of the dolomitic facies perhaps indicate a change from subtidal-intertidal tc supratidal conditions.

AGE CONSIDERATIONS

It has been now widely acknowledged and established that characteristic form assemblages of stromatolites could be safely taken into consideration for the purpose of stratigraphic age and correlation (Raaben,1969; Cloud & Semikhatov, 1969; Walter,1972; Serbryakov & Semikhatov, 1974, etc.). Cloud & Semikhatov have summarised the characteristics and have ranges of stratigraphically significant columnar stromatolites in USSR as shown in table VII.4.

Misra & Valdiya (1961) studied stromatolites from the Calc Zone of Pithoragarh of Kumaon Himalaya and on the basis of similarities of these forms with those described by Fenton and Fenton (1933, 1937, 1939), ascribed them to the genus <u>Collenia</u>, postulating a probable Late Precambrian to Early Ordovician age. Valdiya (1969) recognised and described Middle Riphean stromatolites from the Gangolihat Dolomite, Deoban and Lower Shali Limestones near Simla and compared these structures with Precambrian forms of Vindhyan formations. On the basis of resemblances with the Russian forms, he suggested Lower Riphean (> 1260 my) age for the Fawn limestone of Semri series, and Middle Riphean (1260 - 1000 my) age for Gangolihat Dolomites of the Calc Zone of Pithoragarh, Lower Deoban limestones of Dehradun district, the Tundapatthar limestones of Ambala district and Lower Shali limestone of Sutlej

Table VII.4 Characteristics and ranges of stratigraphically significant columnar stromatolites in the USSR

'Genus'	Shape and ornamentation of column	type of branching	shape of growth laminae	stratigraphic range	central zone
Conophyton	subcylindrical connected or discrete	non branching	conical with axial interruption	Pre-Riphean (2600 ± 100 my) to Vendian (570 ± 10 my) maximum development in Lower and Middle Riphean	sharply defined axial zone
Colonnela	subcylindrical smooth	non branching	strongly convex to domal	Lower and Middle Riphean	non distinctive
Baicalia	tuberous irregularly subcylindrical pustulose	several expanding branching	variably convex	Mostly Middle Riphean to Early Upper Riphean	non distinctive

valley. In general, a Riphean age for Himalayan stromatolites is also supported by Raha and Sastry (1973) Bhattacharya (1976) and Sinha (1977). These above mentioned stromatolitic structures have been generally accepted as algal in origin. Most recently, Mattoo et al. (in press) have shown that the stromatolites of Someshwar area (Kumaon Himalaya) is definitely of biogenic origin and on the basis of the presence of Amino-acids and Fatty-acids proved the presence of low forms of life in these stromalolitic rocks.

The age of the stromatolites developed in the otherwise unfossiliferous sedimentary sequence of the Kali Gandaki valley section has remained a controversial and unsolved problem of Nepal Geology, though some reference to these structures with remarks on their probable geologic ages are found in previous literature. Bordet et al. (1964a) ascribed these structures to the species of Collenia and doubtfully assigned them Devonian age. Bodenhausen et al. (1964) after a preliminary study, suggested the resemblance of these forms with the known Precambrian, Cambrian and Ordovician varieties. Nadgir & Nanda (1966) considered their Suparitar series to be of Post-Delhi period. Fuchs (1967) on the other hand, correlated this dolomite sequence with that of the Krol-Shali rocks of Indian Himalaya and assigned an Upper Palaeozoic to Lower Mesozoic age. Hagen (1969) suggested Mesozoic age for his Nawakot nappes rocks.Talalov(1972), based on the radiometric age determinations gave Upper Proterozoic age to his Hilang Suite (that also includes the dolomitic rocks of the study area). Sharma (1975) considered his Mahabharat limestone group (including the stromatolitic carbonate rocks of the study area, Udaipur, South of Kathmandu valley, Dhadhing and Surkhet) to be of Precambrian to Cambrian age. Correlating these Nepal structures with those of Eastern Siberia, North China and Kumaon Himalaya, Ohta & Akiba (1973) suggested an Eocambrian period for this important stage of algal evolution in Nepal.

Many of the stromatolite structures reported by the present author show close similarity with the Conophyton and Collenia structures of Indian Himalayan regions and Peninsular India (Viswanathiah and Rao, 1967 ; Govind Rajulu and Gowda, 1968; Banerjee, 1971), which have been considered to be of Late Precambrian age (Table VII.5). It is now well established that the Conophyton and Collenia types of stromatolites had their greatest development during the Late Precambrian time. In the absence of recognised invertebrate fossils, the author finds it rather difficult to accept any of the younger ages for these Nepal stromatolite structures postulated by many earlier workers. Therefore, he is of the view that the earliest stage of algal evolution in Nepal also commenced somewhere in the Lower Riphean, and continued through the

Middle Riphean. Valdiya (Personal communication) who has also observed some of the stromatolites from Dolomitic rocks of Dhadhing area (= Phoksing Dolomite) east of Pokhara has attributed one of the forms to be Kussiella of Lower to Middle Riphean age.

The stratigraphic age considerations of the Kali Gandaki rocks in general have already been discussed in Chapter VI.